



Wind Farm Optimization and Multi-Fidelity Wake Modelling

Presentation of TOPFARM I & II, FUSED-Wake

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Wind Farm Optimization and Multi-Fidelity Wake Modelling

Presentation of **TOPFARM I & II**, **FUSED-Wake**

Pierre-Elouan Réthoré et al.

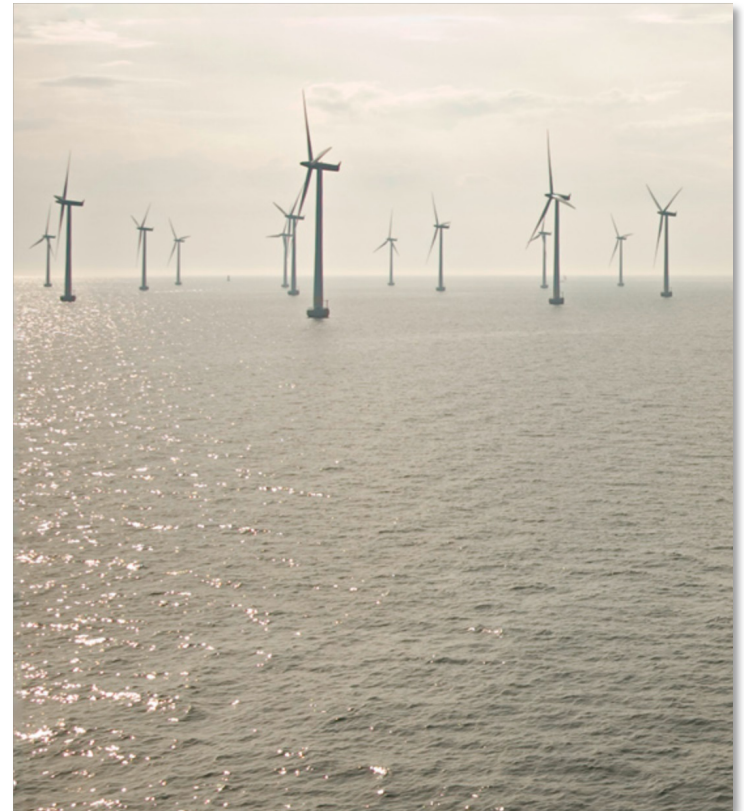
Senior Researcher

Aero-Elastic Design Section

DTU – Wind Energy, Risø

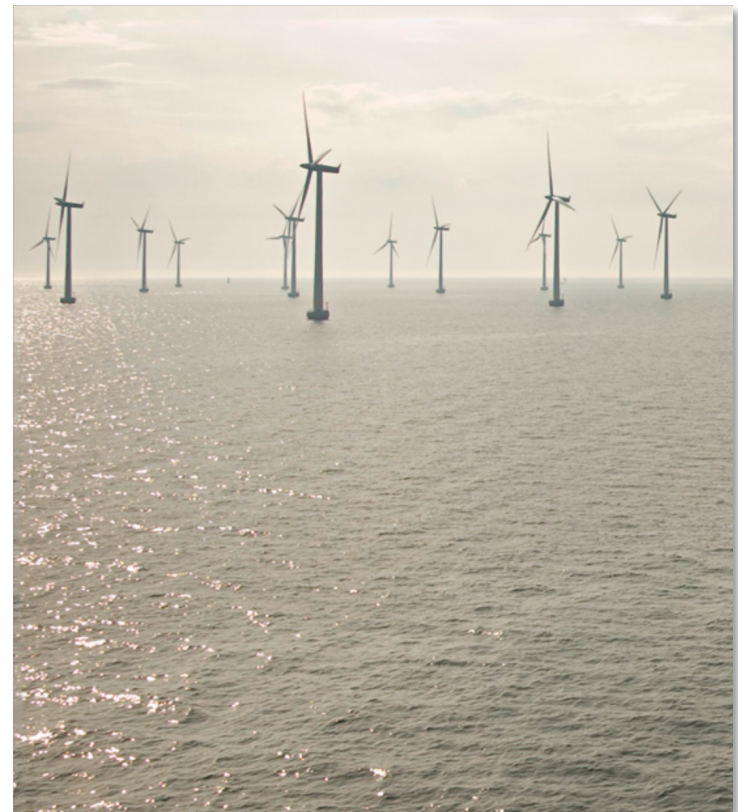
DTU Wind Energy

Department of Wind Energy



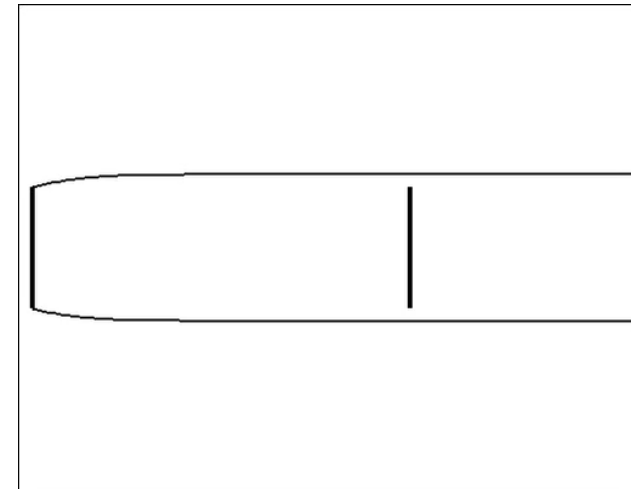
Outline

- Background
- TOPFARM
 - Main Idea
 - System Overview
 - Some Results
 - Feedbacks from the industry
- FUSED-Wake
- TOPFARM II
 - Main Ideas
 - System Overview
- Conclusions



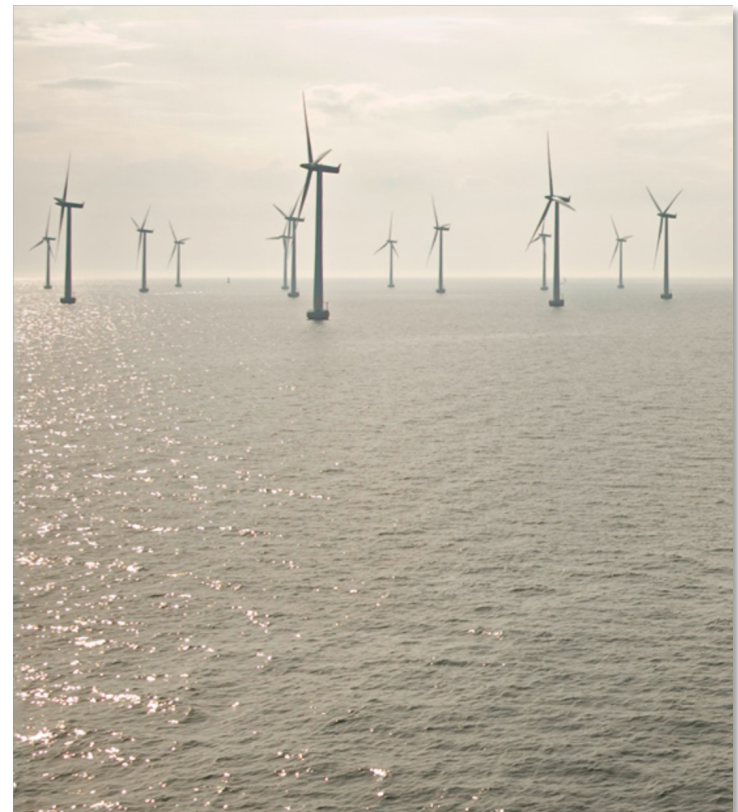
Background

- Aero-Elastic Design Section is principally interested in wind turbine design
- Wind turbines design depends of inflow inputs (upstream wakes)
- Dynamic Wake Meandering (DWM) can calculate wake induced loads
- Other wake models can calculate power production (e.g. FUGA)
- How can we introduce these tools together into wind farm design?



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TOPFARM

Main Idea

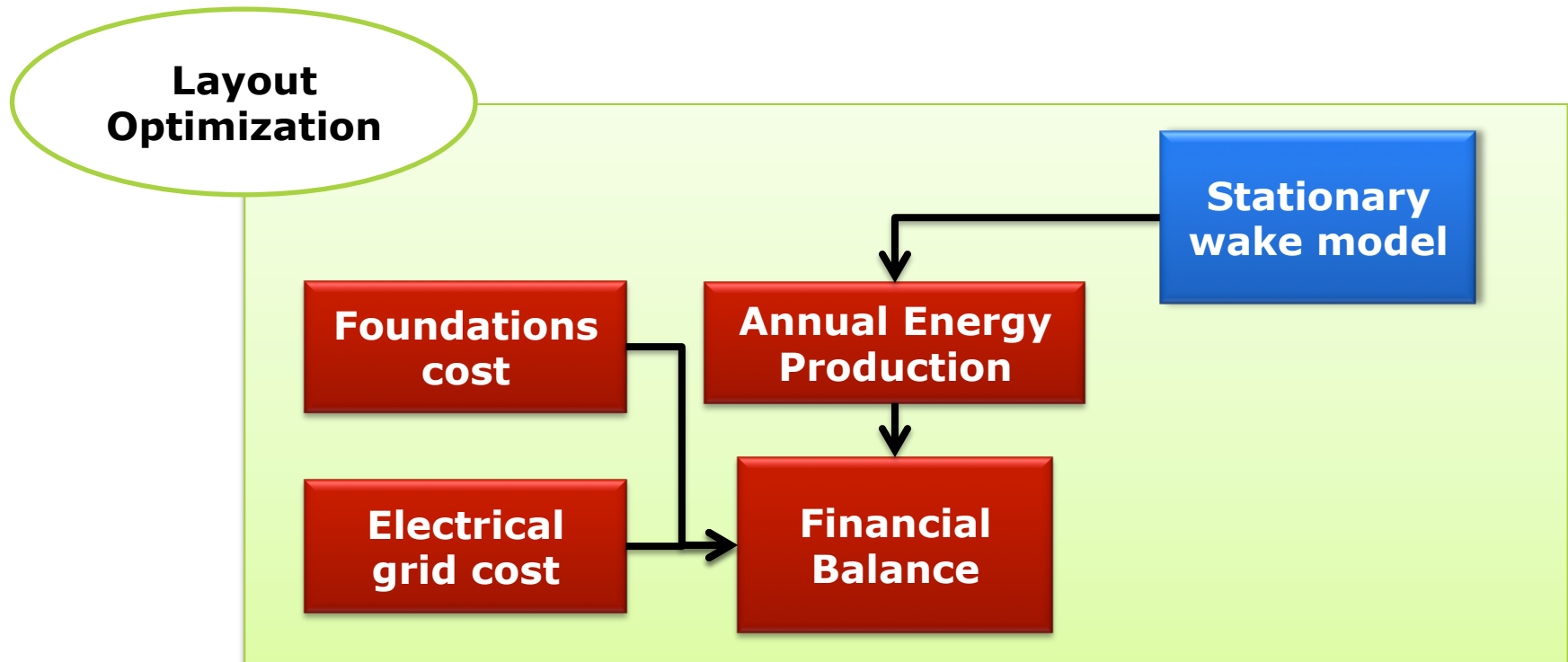
- **TOPFARM** = **T**opology **OP**timization of wind **FARM**
- **EU-FP6** Funded project 2006-2010
- **Multi-fidelity** framework for wind farm layout optimization
- Optimization from the **wind farm developer** perspective
- Objective function is the wind farm lifetime **financial balance**
- The cost models take into account:
 - Wake effects on power production
 - Wake effects on wind turbines components fatigue
 - Offshore foundation costs
 - Electrical grid cabling
 - Financial parameters

TOPFARM

System Overview

Multi-fidelity: 1st Level

Optimization: Gradient based



TOPFARM System Overview

Multi-fidelity:
2nd Level

Optimization:
Gradient based

**Meta
model**

**Dynamic Wake
Meandering
model**

**Aero-elastic
model
(HAWC2)**

**Layout
Optimization**

**Stationary
wake model**

**Foundations
cost**

**Annual Energy
Production**

**Fatigue
induced costs**

**Electrical
grid cost**

**Financial
Balance**

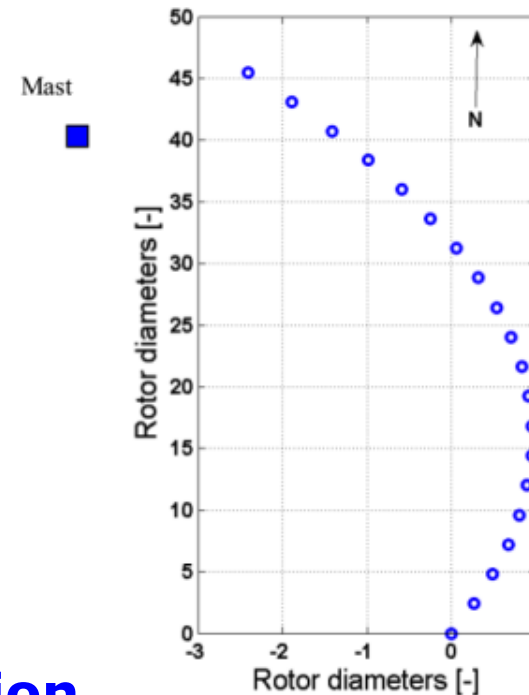
TOPFARM

Demonstration example

- Middelgrunden



Allowed wind turbine region

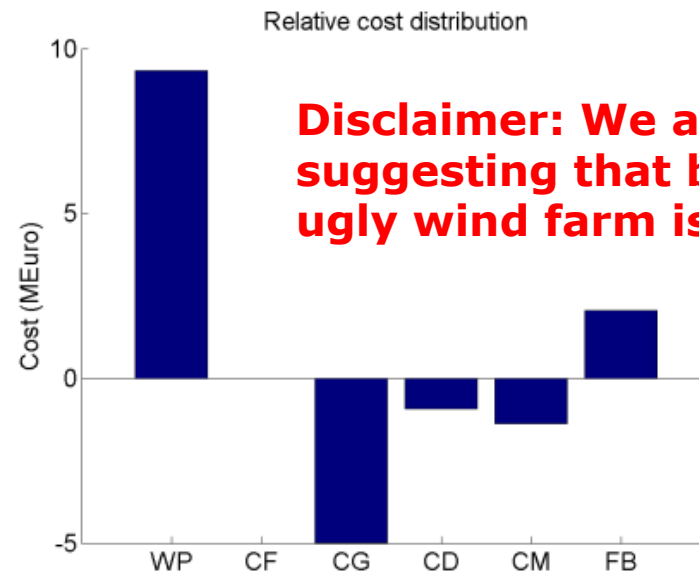
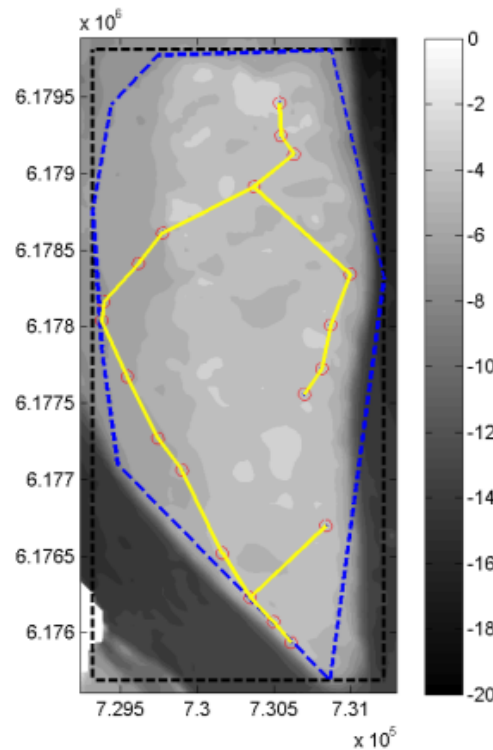


Middelgrunden layout

TOPFARM

Demonstration example

- Middelgrunden iterations: 1000 SGA + 20 SLP



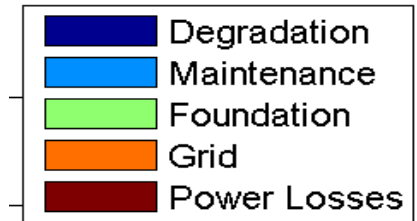
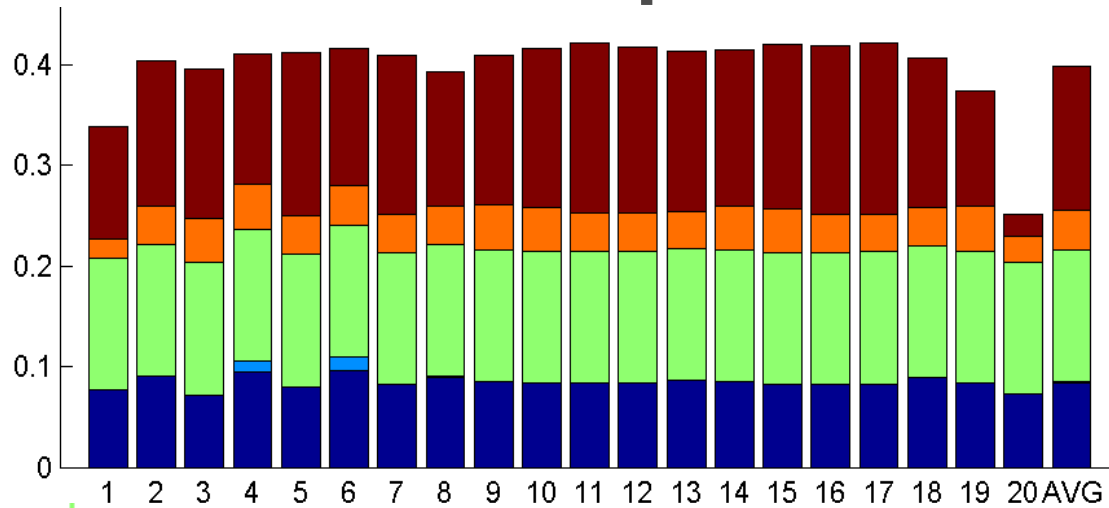
Disclaimer: We are not suggesting that building this ugly wind farm is a good idea

Optimum wind farm layout (left) and financial balance cost distribution relative to baseline design (right).

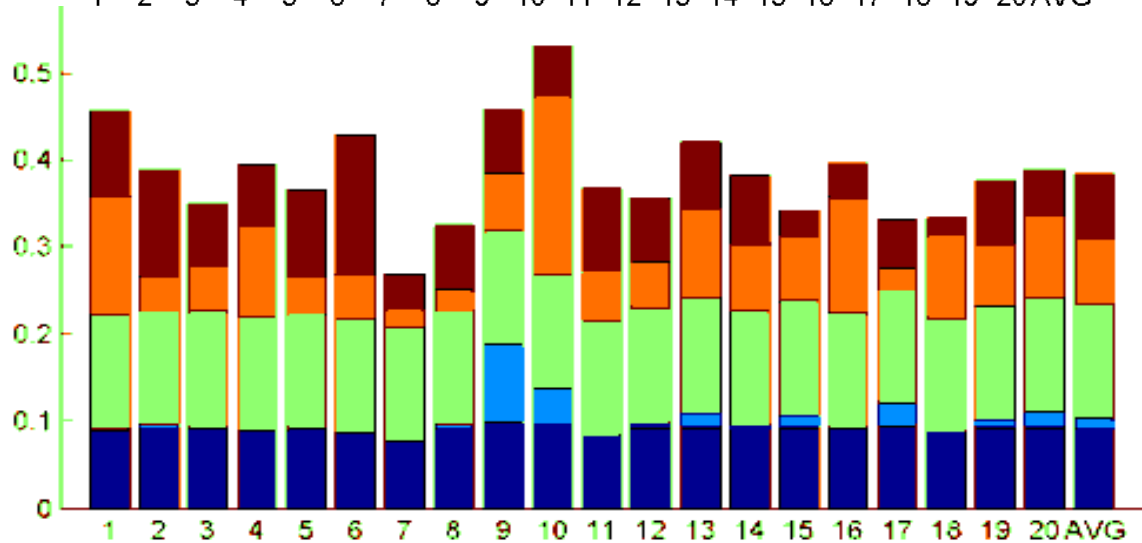
TOPFARM

Demonstration example

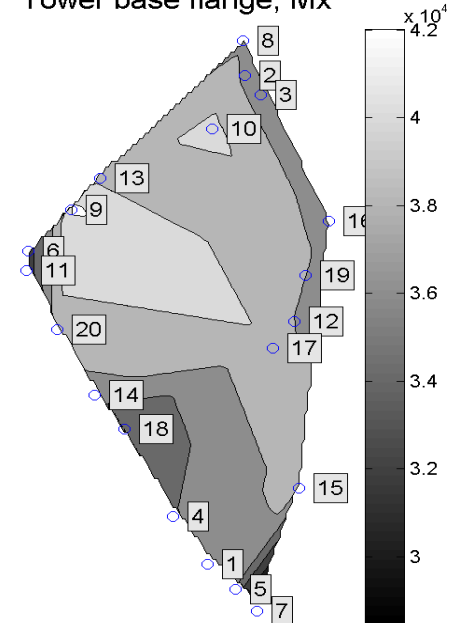
Before



After



Tower base flange, Mx



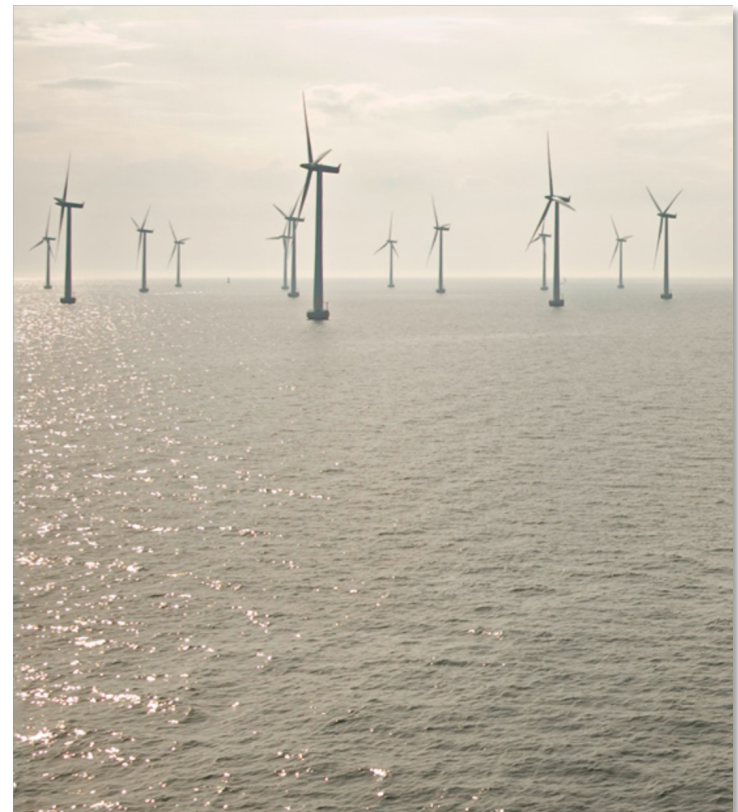
TOPFARM

Feedbacks from the wind industry

- Nice to be able to estimate the wake induced fatigue
- Workflow not ready for a *push-of-a-button* holistic solution
- Multi-disciplinary design tools are difficult to be use in large “bureaucratic” organizations.
- Integrate the expert(s) opinion(s) within optimization loop, *somehow*
- Wish for an open framework, to use their own cost & physical models they already have experience with.

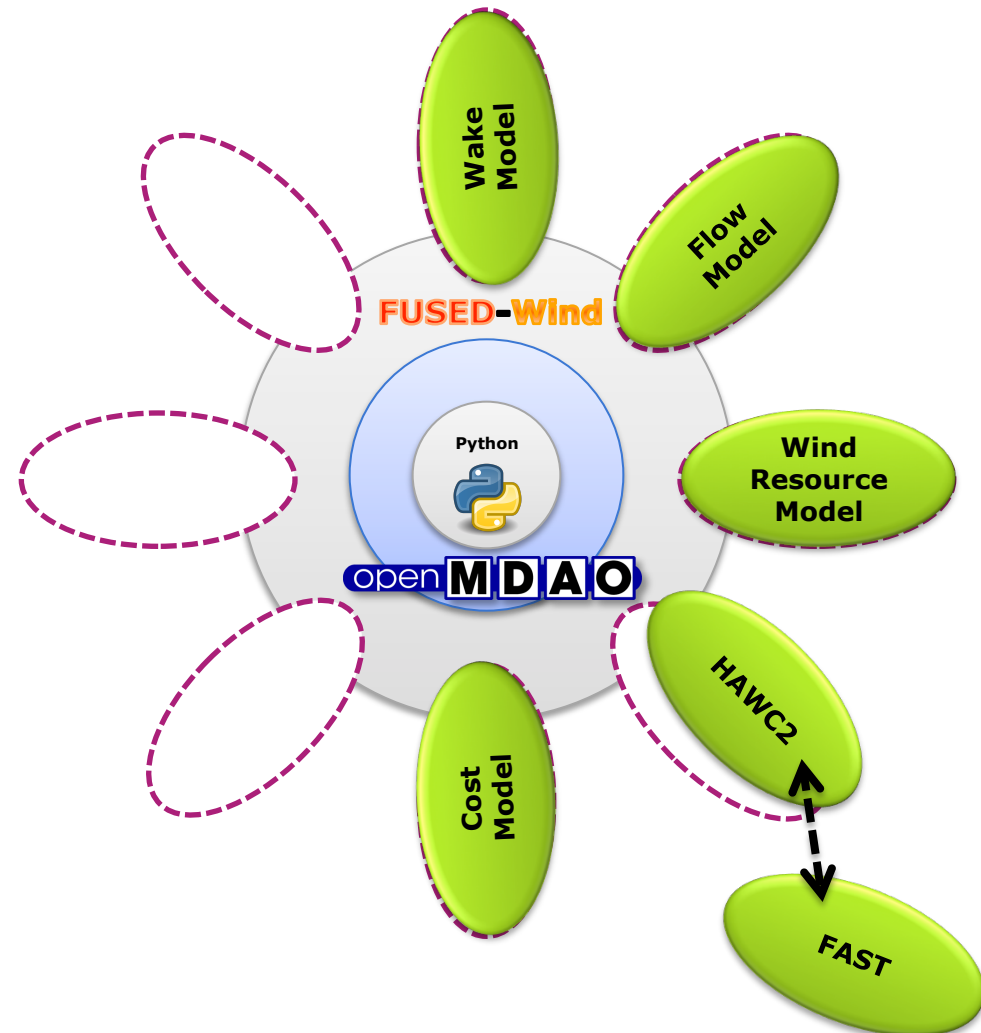
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FUSED-Wind

- Collaborative effort between **DTU** and **NREL** to create a **Framework for Unified System Engineering and Designed of Wind** energy plants.
- Based on OpenMDAO, a python based **Open** source framework for **Multi-Disciplinary Analysis and Optimization**.



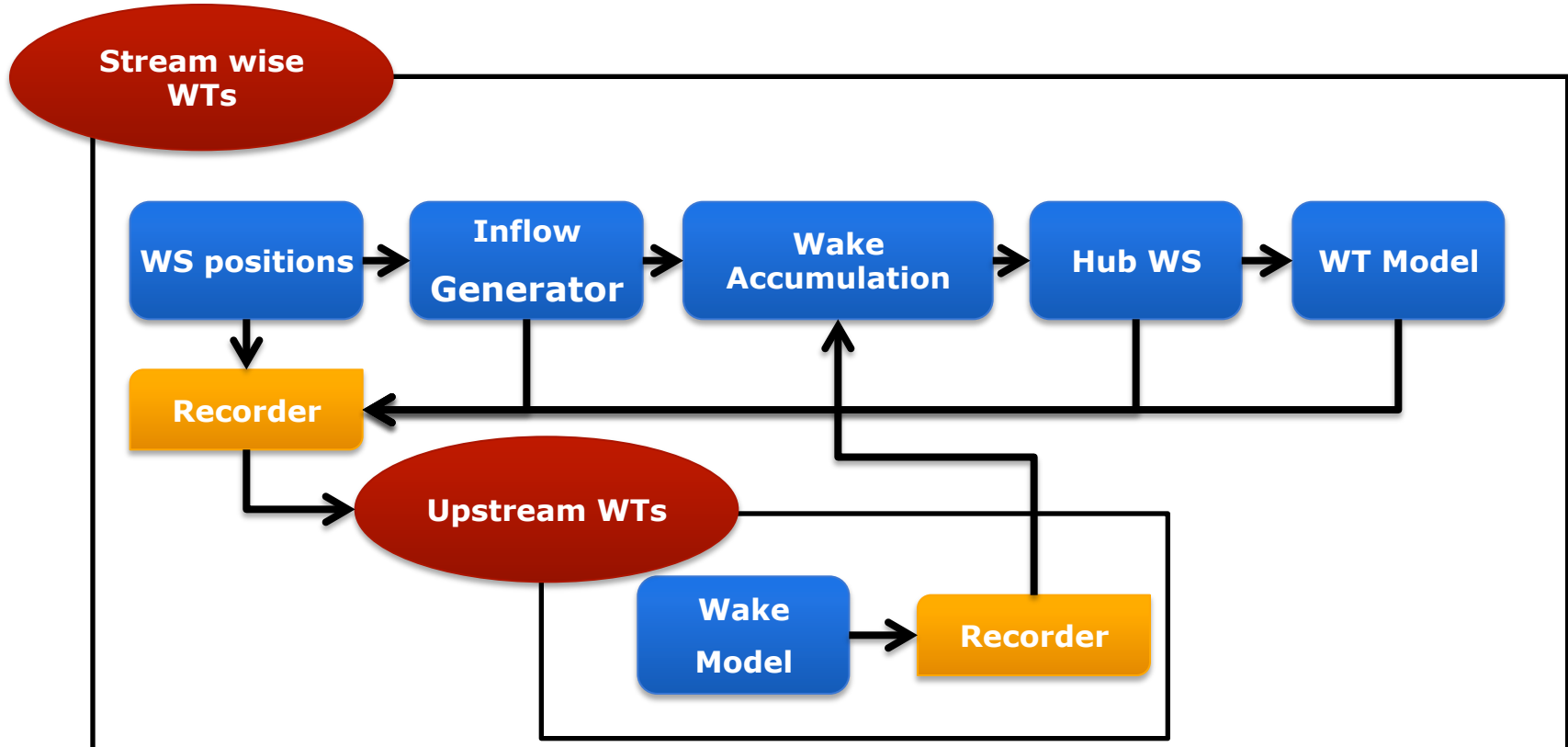


FUSED-Wake

- Collaborative open source tool developed by DTU
- General purpose (AEP, Loads, Optimization, steady/unsteady)
- Modular (workflow divided in sub components)
- Each component is "swappable"
- Each component have multiple fidelity levels
- Derivatives friendly (faster Uncertainty Quantification & Optimization)
- **Open Source** framework + Closed source subcomponents
- Alpha version is ready for testing

Research tool: Modularized concept

- The wind farm wake models are split into a generalized workflow



Potential applications of the framework

- Model automatic selection
- Model Averaging (combining the information of several models)
- Machine learning (systematic model recalibration)
- Uncertainty quantification
- Multi-fidelity optimization
- Robust optimization
- Standard way to run wind farm models
- Bridging the gap between researchers and industry

FUSED-Wake: Status

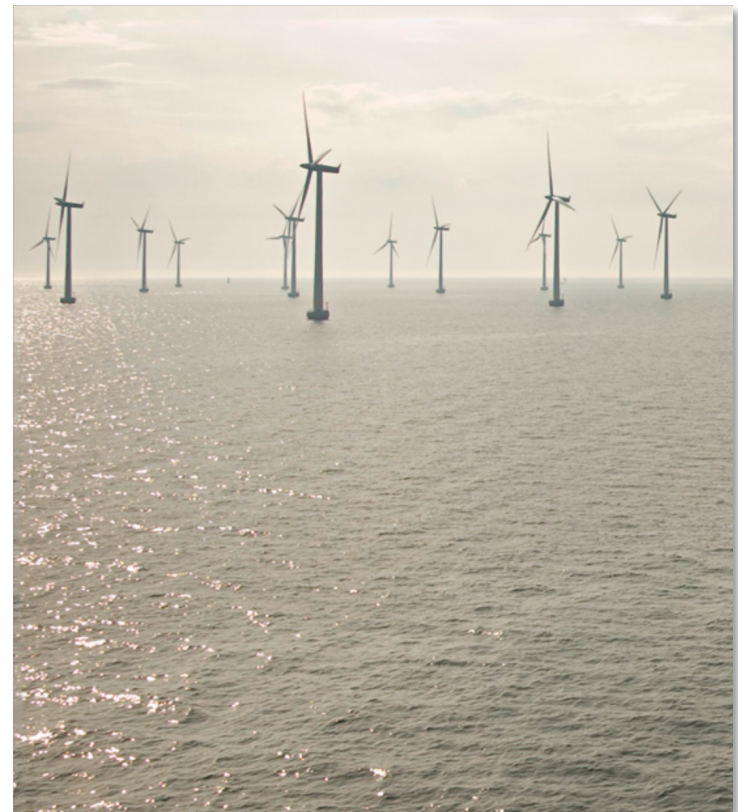
- Framework in alpha version is ready for testing
 - N.O. Jensen
 - G.C. Larsen
 - FUGA
 - EllipSys
 - DWM

Next steps

- Gathering interest group
- Alpha release to interest group
- Public release of beta version
- Forming a project portfolio to coordinate the efforts

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TOPFARM II

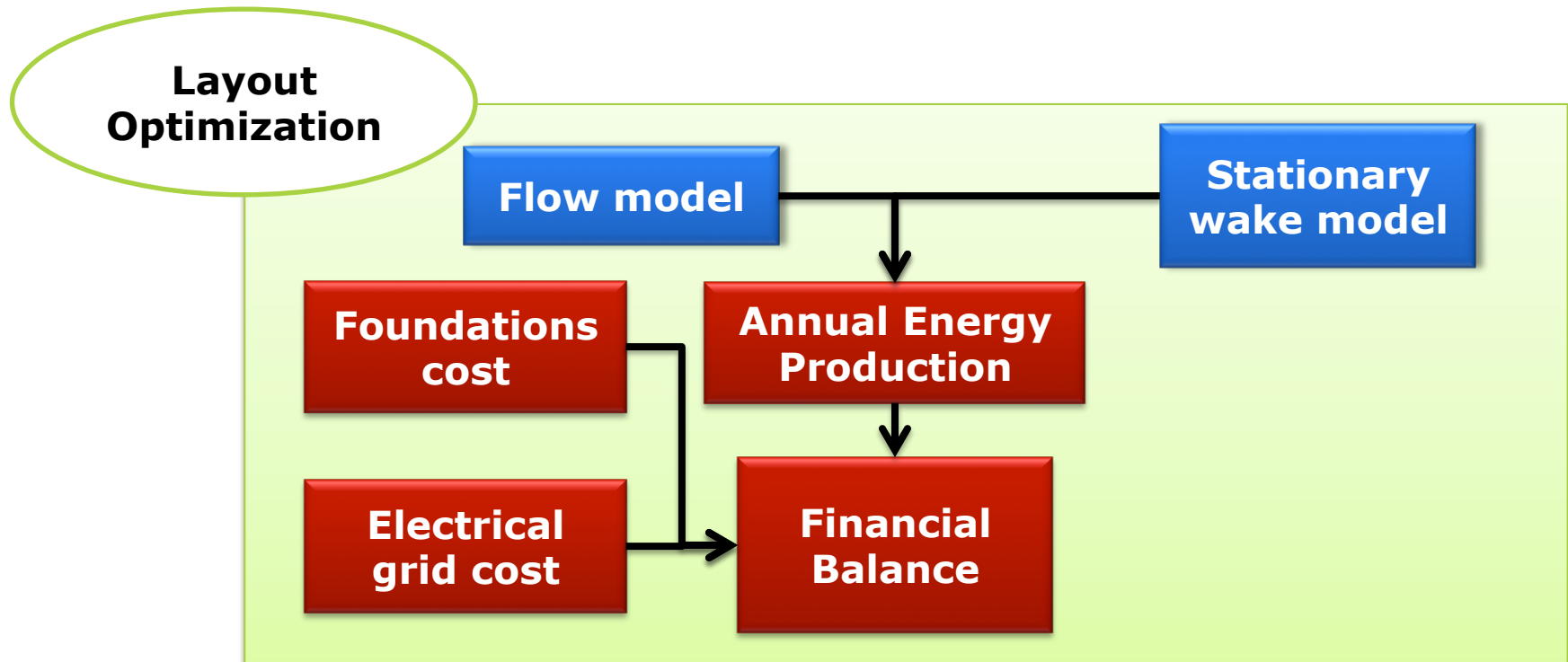
Main Ideas

- Framework based on **FUSED-Wind**
- Use **WAsP** & **WRF** engine to calculate accurate local wind resources
- Multi-fidelity wake model based on **FUSED-Wake**
- 3rd level of fidelity: running the whole wind farm with dynamic wake models (**DWM & AL/LES**)
- More advanced multi-fidelity optimization strategy
- Higher degree of parallelization
- Expert driven iterative design process
- GUI connected to **WAsP**

TOPFARM II

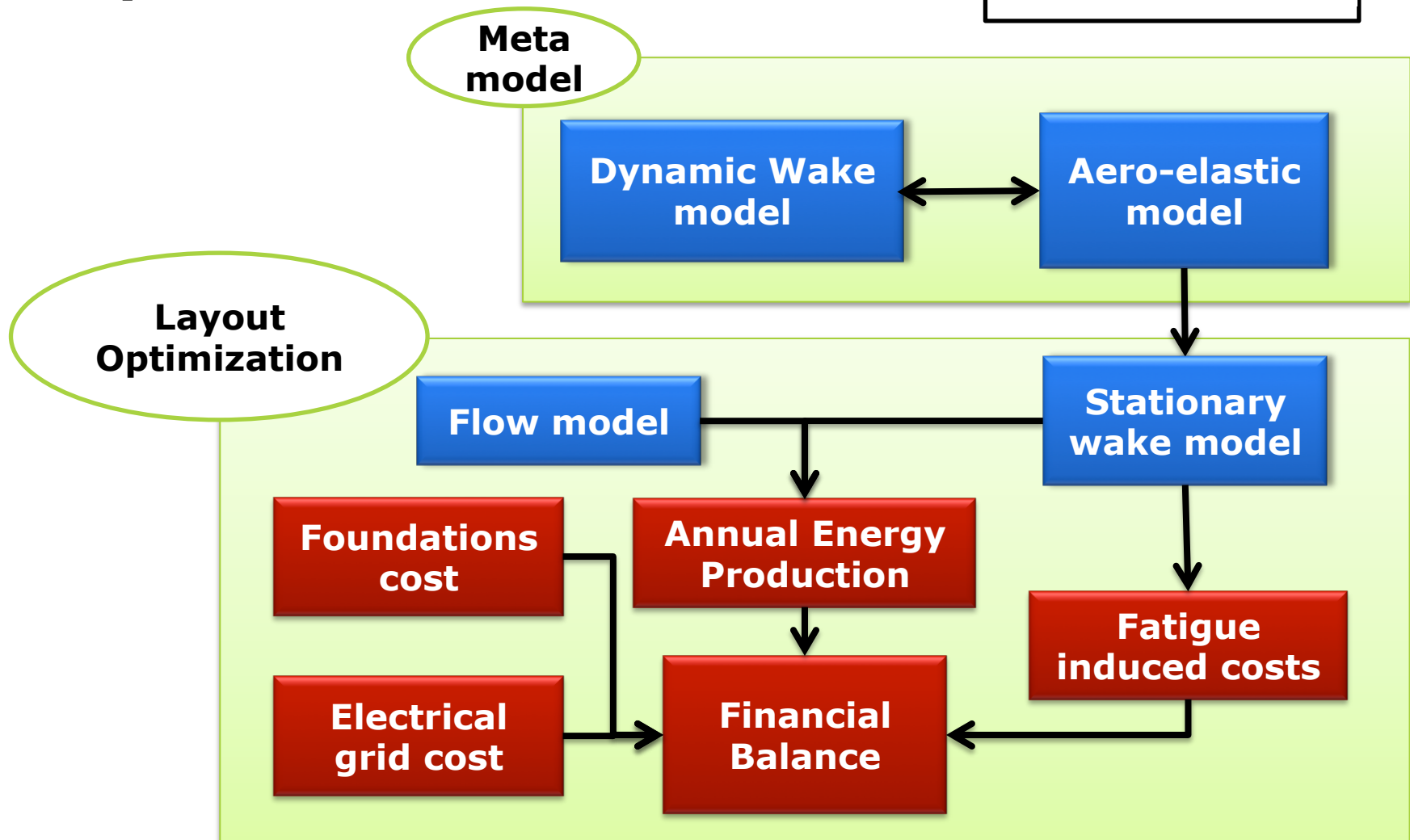
System Overview

Multi-fidelity:
1st Level



TOPFARM II System Overview

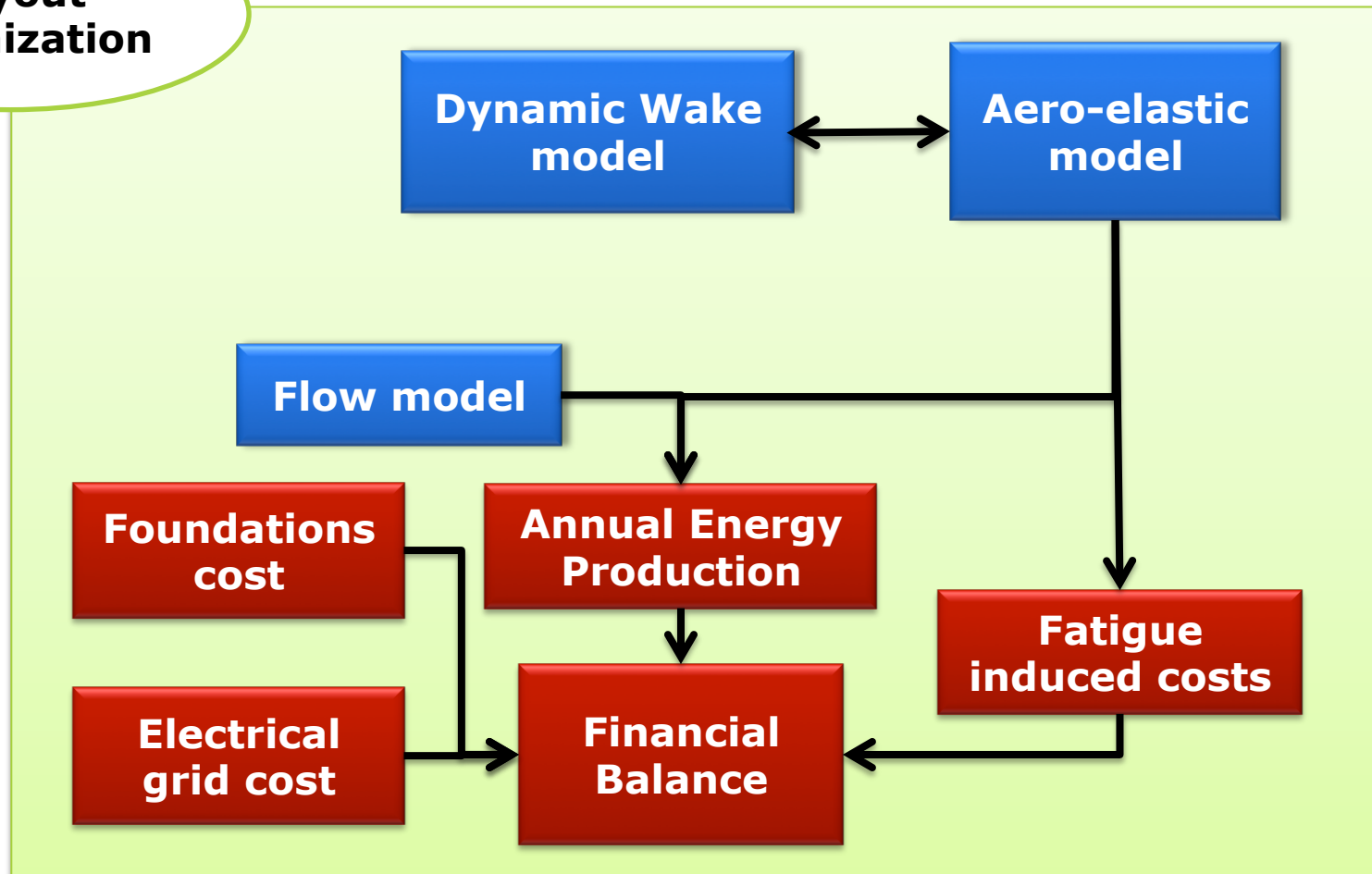
Multi-fidelity:
2nd Level



TOPFARM II System Overview

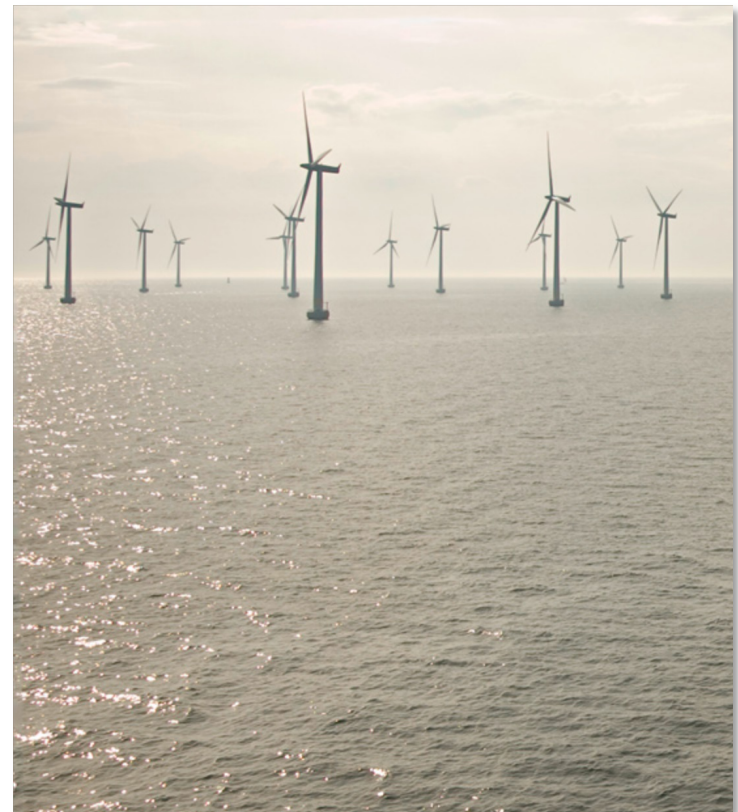
Multi-fidelity:
3rd Level

**Layout
Optimization**



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Conclusions

- When we design a system, you have to take the user into account
- “press-of-a-button” is not expert friendly
- Multi-disciplinary = Multi-user = Communication “challenges”
- Open framework is important
- Wake induced fatigue is relevant for wind farm design & optimization

